INTERMOUNTAIN STATION
Central Reference File
No. 0.73

FOREST SERVICE - U. S. DEPARTMENT OF AGRICULTURE

PACIFIC SOUTHWEST
FOREST AND RANGE
EXPERIMENT STATION
BERKELEY - CALIFORNIA

RESEARCH NOTE

FOREST SERVICE
RECEIVED
JUL 21 19
RESEARCH
INTERMOUNTAIN

No. 180

April 1961

COLD AIR DRAINAGE IN FOREST OPENINGS

By
Allan J. West

While analyzing snow course data of the Cooperative Snow Research Program 1/, we found that the maximum accumulation in forest openings was always in their downslope segment. 2/ In 29 openings of different slopes, aspects, and sizes, an average of 2 inches more water equivalent accumulated in the downslope segment of the opening than in the upslope. Knowledge of the reason for this difference might suggest ways to manipulate snow accumulation. Therefore, using data from four small natural forest openings, we explored some possible alternative hypotheses, such as snow creep, water drainage, evaporation, and evaporative cooling.

The openings chosen for study were on north, south, east, and west slopes of 20 to 40 percent gradient. They were chosen so that the distance across the opening was 1/2 to 1 times average height of the surrounding trees. Snow courses were established in these openings in the summer of 1957 and were sampled in the winters of 1958, 1959, and 1960. The courses sampled all parts of the openings and surrounding forest, but for this study analysis, only those points in the open were used. These points, 6 to 10 in each opening were divided into two groups, the upslope segments and the downslope segments (fig. 1), half the points being in the upper half of the opening and half the points in the lower.

1/ The California Cooperative Snow Management Research Program has been conducted since July 1956 by the Forest Service, Pacific Southwest Forest and Range Experiment Station with the cooperation of the State of California, Department of Water Resources.

2/ Anderson, H. W., Rice, R. M., West, A. J. Snow in forest openings and forest stands. Soc. Amer. Foresters Proc. 1958: 46-50.

CENTRAL FILE COPY

Contour maps of the openings were used in grouping the points into the upslope or downslope segments. Snow samples were taken throughout the winters to determine depth and water content. Evaporation and air temperature measurements were taken in the north slope opening.

Each year in all of the openings, regardless of aspect, there was at least 3 inches more water equivalent in the downslope segment than in the upslope segment; the maximum was 13 inches, and the average 6.6 inches (table 1). This is a large difference in water, and cutting methods designed to take advantage of this in management for delayed water delivery have been described. 2/ The north slope had a consistently smaller difference between its two segments. This would be expected since the downslope segment of a north slope opening is also the area most exposed to the sun.

Table 1.--Average maximum snow water accumulation, by aspect and segment of opening, 1958-1960

Year and aspect	Downslope segment	Upslope segment	Difference
	Inches		
1958			
North	80.0	77.0	3.0
South	67.8	60.6	7.2
East	53.4	46.4	7.0
West	68.6	59.0	9.6
1959			
North	34.4	31.0	3.4
South	28.1	23.8	4.3
East	22.5	17.7	4.8
West	31.2	22.2	9.0
1960			
North	39.4	35.4	4.0
South	32.5	23.4	9.1
East	24.3	19.1	5.2
West	34.8	21.7	13.1

Why should a difference exist in all aspects? One possibility is that snow creeps downward in the opening. However, study of the data point by point does not bear out this hypothesis. In figure 1, for example, the data at individual points are quite consistent for each of the three years, but the maximum snow at any one point is not at the very bottom of the opening. If snow creep were the major factor, one would expect the maximum snow to be accumulated at the bottom edge of the opening next to the trees. Also one would expect snow that creeps downslope

CENTRAL FILE COPY

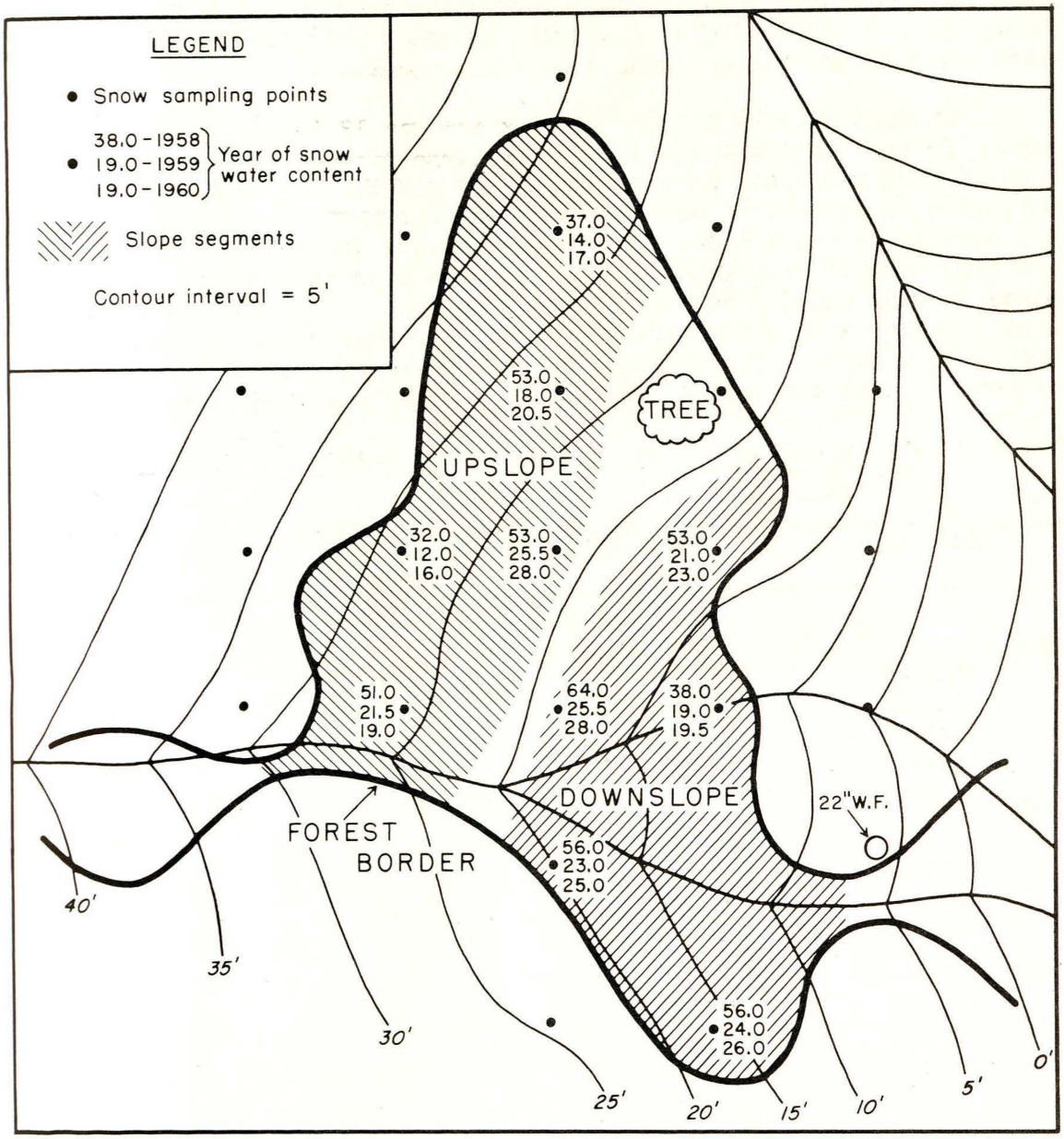

Figure 1.--Opening No. 18, Central Sierra Snow Laboratory. Slope--25%; aspect--93° Az.; average height trees--90 ft.; opening size--1/2 to 1 H; elevation of 6,740 ft. = 20 ft. on map; spacing between sample points--30 ft. Mixed pine-fir forest.

to be denser at the bottom of the opening. But there was no consistent greater snow density in the lower part of any opening except on the north slope and here the increase was not significant (table 2). This north-slope exception, too, can be explained by greater exposure to the sun. This, then, would indicate that creep is not a principal cause for more snow water accumulating in the downhill segments.

Another possibility to consider is the effect of rain on the snow. In each of the three winters 1958, 1959, and 1960, we had from 6 to 10 inches of rain before the time of the maximum pack. Some of this rain could have flowed laterally through the pack from the top of the opening to the bottom. Unless there was a dip in the bottom of the opening, however, the water should continue down through the trees. Also, since snow is usually coarser at the bottom of an opening, lateral movement of water should be increased there. If rain water had ponded at the bottom of a forest opening, snow density would be greater in the downslope segment, but no consistent increase in density was found (table 2).

Table 2.--Average snow density by aspect and segment of openings, 1958 - 1960

Year and aspect	Downslope segment	Upslope segment	Difference
	Percent		
1958			
North	42	41	+1
South	46	45	+1
East	46	46	0
West	46	47	-1
1959			
North	40	39	+1
South	33	35	-2
East	39	39	0
West	38	40	-2
1960			
North	51	47	+4
South	46	45	+1
East	40	39	+1
West	47	45	+2

A third cause to be considered is snow evaporation losses and resultant evaporative cooling. In general, evaporation in small forest openings in the Sierra Nevada is only about 1 to 1.7 inches of water per season.3/ This is a relatively small amount for an average snowpack of about 50 inches.

3/ West, A. J. Snow evaporation and condensation. Western Snow Conf. Proc. 1959: 66-74.

Evaporation was measured at three locations--downslope segment, upslope segment, and in the center-- of the north slope opening--by repeated weighings of snow. Temperature and humidity were recorded in small portable instrument shelters located at the top and the bottom of the opening.

During the 11-day period of measurement, there was 0.08 inch more evaporation in the upslope segment of the opening than in the downslope segment (table 3). Also, the average minimum temperature was 1.9 degrees higher in the upslope segment. In every 24-hour period there was less evaporation and lower minimum temperature in the downslope segment than in the upslope segment. Hygrothermograph records during the eleven-day period showed that hourly temperatures were lower in the downslope segment 43 percent of the time, lower in the upslope segment 38 percent of the time, and the same in both segments 19 percent of the time. The difference is small, but we must remember that the downslope segment of this north slope is exposed to the sun during the day while the upslope segment is shaded.

Table 3.--Evaporation and nightly minimum temperature in a small north-facing forest opening

Date	Evaporation			Minimum temperature		
	Top	Center	Bottom	Top	Bottom	Difference
	Inches of water			Degrees centigrade		
5/9-10	-0.022	-0.015	-0.015	+4.1	-0.1	4.2
5/10-11	-0.014	-0.011	-0.004	+4.9	+1.2	3.7
5/11-12[1/]	+0.013	+0.010	+0.013	+2.0	+1.2	0.8
5/12-13	-0.030	-0.021	-0.021	-4.1	-6.8	2.7
5/13-14	-0.024	-0.016	-0.014	0.0	-2.5	2.5
5/14-15	-0.018	-0.010	-0.005	-0.8	-3.6	2.8
5/15-16	-0.009	-0.009	-0.006	+0.2	-0.5	0.7
5/16-17	-0.024	-0.017	-0.014	-1.2	-2.5	1.3
5/17-18	-0.029	-0.031	-0.026	-2.8	-3.7	0.9
5/18-19	-0.038	-0.027	-0.029	-2.8	-3.4	0.6
5/19-20	-0.013	-0.010	-0.010	+1.0	+0.2	0.8
Total 11 days	-0.208	-0.157	-0.131	--	--	Ave. diff. 1.9

1/ + indicates condensation.

Comparing these measurements with data from a control evaporation site 4/ which lost 1.14 inches of water in the 1960 season (January 1 - May 20), we found that seasonal evaporation in the upslope segment was 0.64 inch greater than in the downslope segment of the opening. This amount suggests that evaporative cooling in the upslope segment might be a contributing mechanism in supplying cold air for drainage. We have seen that minimum temperatures are lower in downslope segments, they persist for a longer period, and the water content of snow is greater. Geiger noted that cold air drained downslope and that it tended to pond when there was a good barrier at the base of the slope or even part way down the slope. 5/ We can hypothesize that trees at the bottom of a forest opening act as a barrier and cause the cold air to pond. This ponded cold air in turn slows down melting (snow melts throughout the accumulation season in the Sierra Nevada of California). Cold air drainage, then, seems to have the most effect on the snow pack, causing accumulation to be greatest in the downslope segments of forest openings.

4/ Evaporation was measured daily at a control station from time of the first snow until all snow melted.

5/ Geiger, R. The climate near the ground. Harvard University. 482 pp., illus. 1957. (pp. 195-203)